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In-line EUV beam monitoring using microwaves

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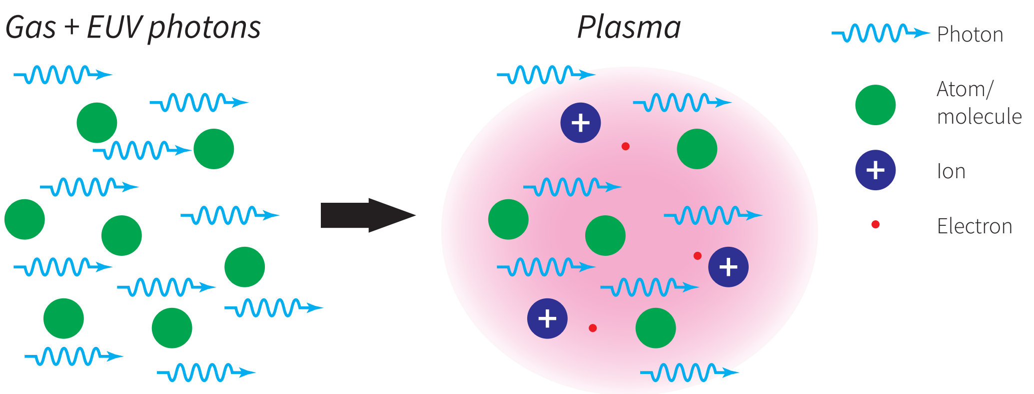
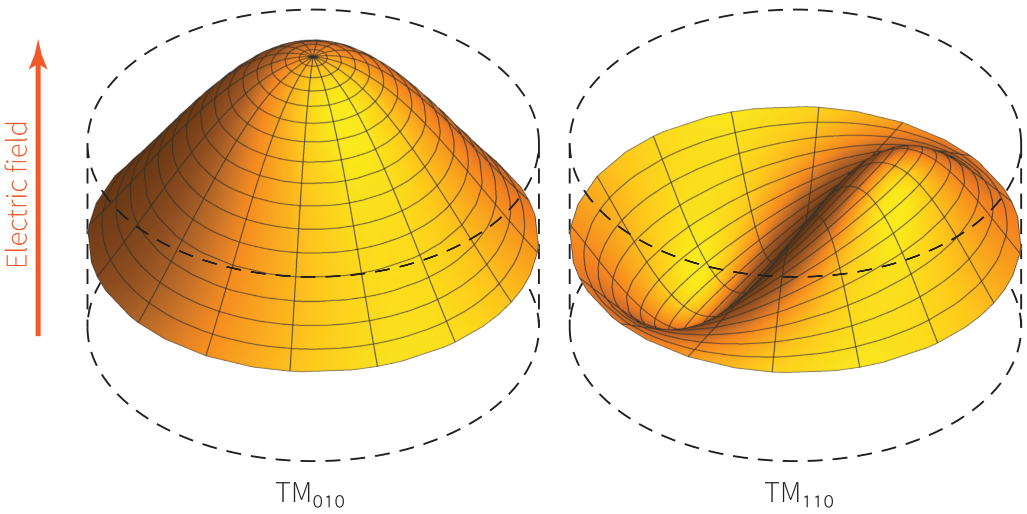
Dosimetry of EUV/X-ray pulses



Concept:
Measure distribution of electrons
Ionization cross sections ➔ Radiation profile

Device: microwave cavity resonator

Excite standing EM waves in metal cavity. Examples:

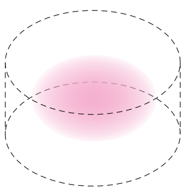


Permittivity of medium determines **resonance frequency:**

For mode TM_{mnp}: $$\omega_0 = \frac{c}{\sqrt{\epsilon_r}}\sqrt{\left(\frac{x_{mn}}{R}\right)^2 + \left(\frac{\pi p}{d}\right)^2}$$

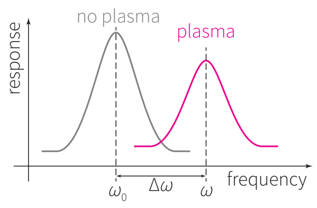
speed of light; root of Bessel function; cavity radius; cavity height

Plasma changes resonance frequency (Slater perturbation theory):

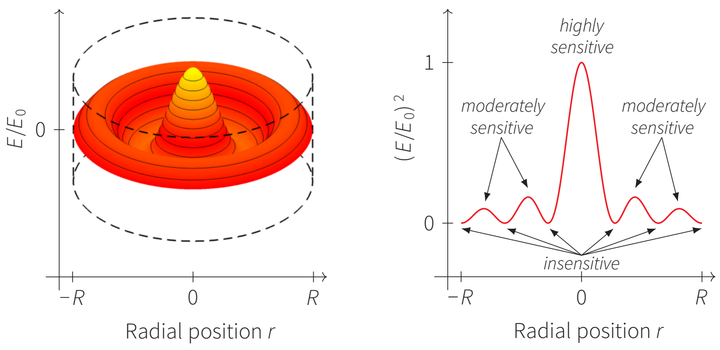


$$\Delta\omega = \frac{\omega_0 e^2}{2\omega^2 m_e \epsilon_0}\frac{\iiint n_e(\mathbf{x})|\mathbf{E}(\mathbf{x})|^2\, d^3\mathbf{x}}{\iiint |\mathbf{E}(\mathbf{x})|^2\, d^3\mathbf{x}}$$

spatial distribution of free electrons; electric field magnitude of resonant mode



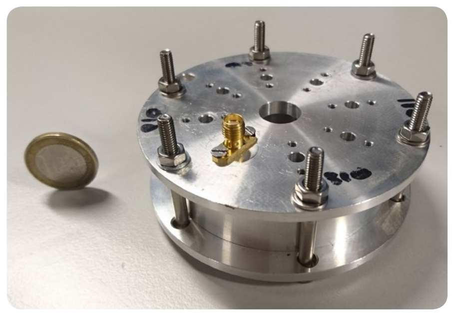
Mode electric field determines ‘sensitivity’ to free electrons:



Combine multiple modes to obtain $n_e(\mathbf{x})$

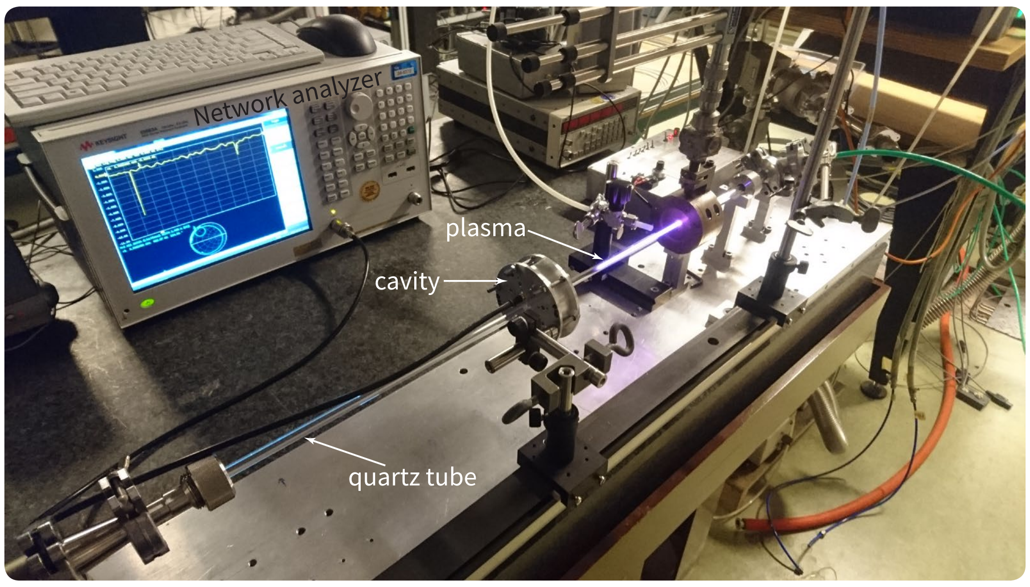
Multimode cavity

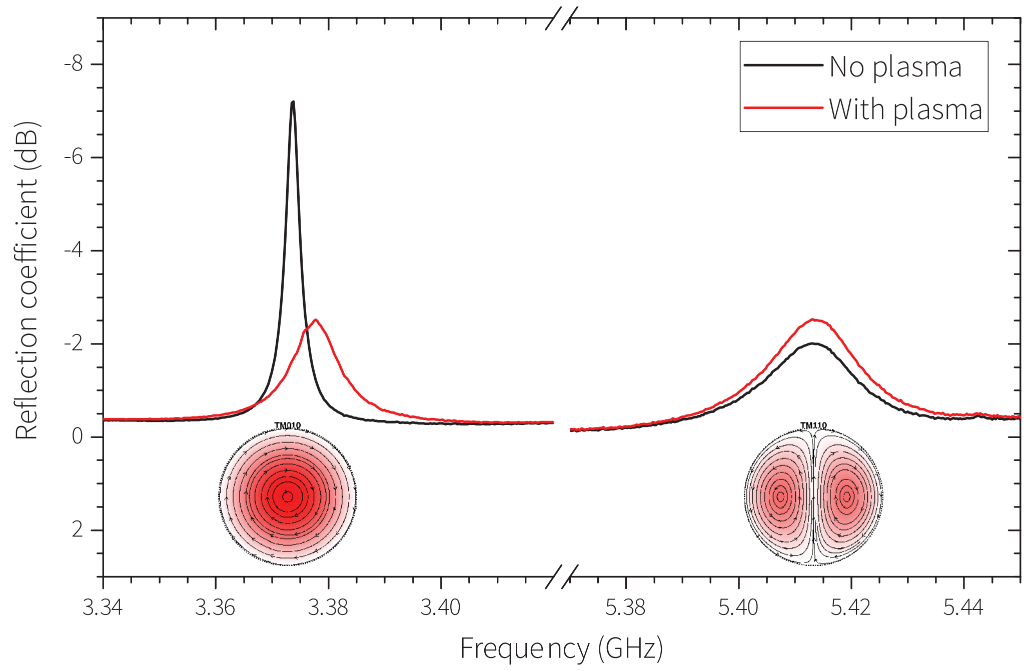
Cylindrical aluminum cavity:



Proof of principle: surfatron plasma

Low-pressure (1 – 100 mbar) argon plasma enclosed in quartz tube:





Estimated performance

Frequency resolution: ~10 kHz ➔ Minimum electron density: ~10^{12} m^{-3}.
$\Delta\omega/\omega_0 < 10^{-1}$ ➔ Maximum electron density: ~10^{16} m^{-3}.
Spatial resolution: < 100 μm.
Temporal resolution: < 100 ns (for reproducible pulsed experiments).

Example in realistic radiation-induced plasma
For 100 eV photons in 10^{-5} mbar N_2: fluence between 10^2 and 10^6 J/m^2.

Second cavity & in-house developed measurement system
Microsecond temporal resolution, but lower minimum electron density possible (~10^{10} m^{-3}).